



# Structure and composition of streamside management zones following reproduction cutting in shortleaf pine stands

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## ABSTRACT

Streamside management zones (SMZs) in the Ouachita Mountains of Arkansas and Oklahoma are frequently established along headwater ephemeral and intermittent streams to protect water quality, provide wildlife habitat, and increase landscape diversity. To better understand the function of these riparian forest corridors, we characterized the tree density and composition, forest floor mass, and downed woody debris volume within SMZs located in undisturbed, mature, upper mid-slope shortleaf pine stands and then compared these attributes to those in upland portions of these stands. In addition to evaluate the impact of upland forest harvesting on these riparian corridors, we compared the amounts and distribution of forest floor, downed woody debris (DWD), snags, and windthrows in SMZs within shortleaf pine stands that had been clearcut, had a shelterwood harvest, and had no recent management activity (uncut stands). Total tree and hardwood basal area was significantly higher ( $4.4$  and  $4.2 \text{ m}^2 \text{ ha}^{-1}$ ) while forest floor mass was significantly lower ( $0.5 \text{ kg m}^{-2}$ ) in the SMZs than in the upland portion of the undisturbed stands. Five years following the reproduction cuttings tree basal area, DWD volume, and forest floor mass within SMZs did not significantly differ among stands that had or had not been harvested. Snag density was significantly lower within SMZs that occurred in clearcut stands compared to those in the uncut or shelterwood stands. Harvesting activities that retain few or no residual trees appear to increase the degradation of snags. This study provided evidence that clearcutting may also increase the risk of windthrow in SMZs as well. There was little difference in the distribution of forest floor within SMZs regardless of whether the stand was harvested or the type of harvesting that occurred in the stand. However, DWD amounts were higher near the SMZs edge than in the interior of the SMZs with the greatest differences in distributions in stands that were clearcut.

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## 1. Introduction

Shortleaf pine (*Pinus echinata* Mill.) is the most dominant tree species and the only native pine in the pine-hardwood forest communities that occur on ridges and upper to mid-slope positions in the Ouachita Mountains. These stands contain much of the headwaters and upper stream reaches of many significant river systems in Arkansas and Oklahoma. Headwater streams in this region flow infrequently, are classified as ephemeral or intermittent, have low stream orders, and have relatively narrow channels and floodplains. Land management agencies, such as the Ouachita National Forest, typically establish buffers or streamside management zones (SMZs) along these streams to protect water quality as well as to maintain other riparian functions (U.S.

Department of Agriculture, Forest Service 1990). Because channels and floodplains (generally less than 40 m) are narrow, SMZ width is also narrow along these headwater streams. Given the infrequent flow of these streams and the narrow width of the SMZs, differences in tree composition and stand characteristics between upland and riparian portions of these stands are likely much less than in stands located along higher order stream segments. Currently there have been few studies that have characterized the composition and structure of these forested corridors in the Ouachita Mountains or other southern upland forests.

Creation of edges through forest harvesting and other management practices has been found to increase windthrow (Gratkowski, 1956; Esseen, 1994), increase tree mortality (Chen et al., 1992; Harper and Macdonald, 2002), alter snag densities (Chen et al., 1992; Harper and Macdonald, 2002; Harper et al., 2004), increase snag breakage (Harper and Macdonald, 2002), increase coarse woody debris volume (Chen et al., 1992; Harper and Macdonald,

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2002), and alter soil processes such as respiration (Zheng et al., 2005). These impacts occur with varying distances from edges depending on stand composition, stand structure, and regional physiography. For example tree mortality and/or snag density in boreal stands with little topographic variation were only altered within the first 5 m of a clearcut edge (Harper and Macdonald, 2002; Harper et al., 2004), whereas edge impacts on mortality in Douglas-fir old growth stands with high topographic variation occurred up to 120 m from clearcut edges (Chen et al., 1992). The distance from the edge in which changes occurs also depends on the stand characteristic or attribute of interest. Harper and Macdonald (2002) found that coarse woody debris volumes in boreal forests were significantly higher within 20 m of clearcut edges while mortality was only significantly higher within 5 m of clearcut edges.

Alteration of mortality, snag density, and windthrow adjacent to stands that are harvested is generally thought to be a result of changes in microclimatic conditions. Trees near clearcut edges frequently suffer wind damage (DeWalle, 1983; Chen et al., 1992) which increases the amount of woody debris near these edges (Chen et al., 1992; Burton, 2002). Generally changes in microclimate occur within one tree height of the edge (15–60 m) with climate factors such as wind speed or soil temperature being mitigated in the forest closer to the edge than air temperature or relative humidity (Moore et al., 2005). If forest patches are small enough, the entire forest patch may become influenced by the management practices outside the stand. For example old growth forest fragments up to at least 1 ha in size were found to be dominated by edge habitat following the harvesting of trees outside the patch (Esseen, 1994).

Harvesting outside of narrow SMZs may have a similar effect. Brosofske et al. (1997) found that a riparian buffer of 45 m on each side of a channel was needed to maintain a natural riparian microclimate within narrow (2–4 m channel width) streams located in harvested forests in Washington. Thus it seems likely that harvesting outside the SMZs along headwater streams may also impact important functions of these riparian corridors in the Ouachita Mountains, but few studies have focused on these questions.

We were interested in whether harvesting outside SMZs in shortleaf pine stands would affect the stand structure, related stand characteristics, and associated riparian functions within these SMZs. In addition we wanted to understand potential differences in stand characteristics between uncut riparian and upland non-riparian areas within mature, unmanaged shortleaf pine stands in the Ouachita Mountains. The objectives of the study were (1) to compare living tree basal area, forest floor mass and downed woody debris (DWD) volume in SMZs to those in adjacent uncut upland shortleaf pine stands; (2) to determine how different reproduction cutting methods outside the SMZs impacts stand density, living tree basal area, forest floor mass, DWD volume, and snag/windthrow density within SMZs; and (3) to investigate the spatial variability of forest floor mass, DWD volume, and snag/windthrow density with SMZs located in mature undisturbed and harvested stands.

## 2. Methods

### 2.1. Study sites

Twelve shortleaf pine stands in the Ouachita National Forest in Arkansas and Oklahoma were used for our study. These stands were part of a larger research project studying the impacts of different reproduction cutting methods on seed production, vegetation dynamics, wildlife populations and various other biotic and abiotic parameters (Guldin, 2004). Each stand was between 14

and 16 ha in size, was mature with dominant tree ages >70 years, and was located on south to southwest-facing slopes (Baker, 1994). In 1993 four of these stands were clearcut (CC) and planted to shortleaf pine, four of these stands were harvested using shelterwood (SW) reproduction cutting methods with the goal to retain  $6.8 \text{ m}^2 \text{ ha}^{-1}$  of pine and  $2.3 \text{ m}^2 \text{ ha}^{-1}$  of hardwood, and the other four stands were uncut and used for controls (UC). One of the four clearcut stands did not contain a significant stream or drainage segment and was excluded from the study. Prior to harvesting, the average total basal area (trees with dbh  $\geq 9.1$  cm) in the clearcut, shelterwood, and uncut stands was, respectively  $25.9$ ,  $31.9$ , and  $28.9 \text{ m}^2 \text{ ha}^{-1}$ . One year following the initial harvests, basal area in the clearcut, shelterwood, and uncut stands were, respectively  $0.9$ ,  $11.4$ , and  $27.6 \text{ m}^2 \text{ ha}^{-1}$ . Each stand contained at least one ephemeral or intermittent stream channel which was predominantly headwater streams that extended from the upper or mid-slope portions of the stand to the bottom of the slope. Prior to any harvesting, SMZs boundaries were located along each side of the channel and along each stream in the uncut control stands as well. SMZs were established by Ouachita National Forest employees using the guidelines in the forest management plan at that time (U.S. Department of Agriculture, Forest Service 1990). A minimum 9 m buffer was left on each side of the stream channel, but was increased based on slope and soil erosion hazard (Table IV-14 U.S. Department of Agriculture, Forest Service 1990). Frequently these riparian corridors are incised and the edge of the SMZ extends to the break in the slope associated with the stream incision. No harvesting occurred in the SMZs. A total of 5, 9, and 8 suitable SMZs were, respectively delineated in the CC, SW, and UC stands. Average width of these SMZs (SMZ edge on one side of channel to the edge on the other) was 31.4 m.

### 2.2. Living tree, forest floor and downed woody debris measurement

In 1998, 5 years after harvesting, we established 2–4 plots within each SMZ, depending on the number of SMZs within the stand and length of each SMZ. Plots were located at least 50 m from the end of the SMZ, any stand border, and any adjacent plots. Plots were also located at least 50 m from where a SMZ split to follow forks in the stream channel. Plot length was corrected for slope and spanned the entire width of the SMZ (both sides of the channel). Plot width was 15 m. Lengths of each plot corrected for slope was recorded. Plots were located in 4, 6, and 8 of the SMZs that occurred in the CC, SW, and UC stands, respectively; 9, 13, and 12 plots were established in the CC, SW, and UC SMZs, respectively. Where possible, plots were located at each slope location (upper, middle, and lower).

Dbh and species of trees with a dbh greater than or equal to 9.1 cm was recorded. Forest floor and downed woody debris (DWD) volumes were measured along a transect extending the length of the plot. Measurements were taken at 5 m intervals starting 2.5 m from each end of the plot (SMZ edge) progressing to the center. At each sampling location forest floor was removed from a  $0.1 \text{ m}^2$  area and brought back to the laboratory, dried at  $65^\circ \text{C}$  for 48 h, and then weighed. Woody debris  $\leq 7.5$  cm in diameter on the surface of the forest floor was excluded from the sample. A 15 m DWD transect was centered at each forest floor sampling location perpendicular to the transect running the length of the plot. DWD (diameter >7.5 cm) volumes were determined using a line intercept method (Van Wagner, 1964; Ringvall and Stahl, 1999) along each 15 m transect.

In the uncut stands an additional  $15 \text{ m} \times 30 \text{ m}$  plot was randomly established adjacent to each plot in the SMZs. These additional plots were in the upland portion of the stand at least 50 m from the edge of the plot in a SMZ and oriented in the same direction as the SMZ plot. Forest floor sampling and DWD measurements occurred at 5 m intervals within the  $15 \text{ m} \times 30 \text{ m}$  plots. Living tree

dbh was measured in the same manner as that in the plots located within the SMZs.

### 2.3. Windthrow and snags

To quantify the number of windthrows and snags, several transects were located across the width of each of the SMZs within a stand. Transects needed to be at least 50 m from a stand edge, 50 m from the end of a SMZ, and 20 m from any forks in a SMZ. In addition there had to be at least 30 m between adjacent transects. Transects were located perpendicular to the direction of the SMZ from the edge of one side of the SMZ to the other and the length of each transect was recorded. All snags with heights greater than 2 m and a dbh greater than 9.1 cm within 10 m of the transect and located within the SMZ were found. All windthrows that had their root wads within this 10 m distance were also located. The perpendicular distance from the nearest SMZ edge to each snag or windthrow location was recorded along with whether the snag or windthrow was a pine or hardwood. Dbh of each snag and windthrow was also measured. A total of 88 transects were located within the 11 stands. Average transect length was 32.8 m and a total of 5.6 ha of SMZ were inventoried for snags and windthrows.

### 2.4. Statistical analysis

A paired *t*-test was used to test for differences in tree basal area, forest floor mass, and DWD volume between riparian and upland plots in the uncut control stands. A randomized block design with subsampling was used to evaluate the effects of stand treatment on tree basal area, forest floor mass, DWD volume, snag density, and windthrow density within the SMZs. Since stand selection was done from four regions within the Ouachita Mountains (Baker, 1994) these regions served as the blocks within the design. Plots were used as the subsample within each stand for the all variables except snag or windthrow density. An individual SMZ was the subsample for these other parameters.

Two separate analyses were performed for the DWD and forest floor mass; one included all sampling locations and the other included only the sampling locations at 2.5, 7.5, and 12.5 m from the edge of the SMZ. The first compared the average unit volume or mass in a plot among treatments. The second compared the average unit volume or mass within the first 12.5 m of the edge of an SMZ along with the distribution of these amounts within this area. The 2.5–12.5 m distances were utilized because all but one stand contained plots in an SMZ with total widths of at least 25 m.

When variances among factors for a given parameter were not homogeneous or had distributions that were not normal, measurements were averaged for a stand and a Kruskal–Wallis procedure was used to test for differences among reproduction cutting methods and/or locations (2.5, 7.5, and 12.5 m) from a SMZ edge. Where differences were significant ( $\alpha = 0.10$ ), means were separated using Tukey's HSD test for variables evaluated using parametric tests. Medians were separated with a Dunn's test when nonparametric tests were employed. An overall test  $\alpha = 0.20$  was used with the Dunn's test to maintain an acceptable alpha level for individual median pair comparisons.

A paired *t*-test was used to determine whether snag or windthrow locations were affected by distances to a SMZ edge for different reproduction cutting methods. This was done by comparing the distance from SMZ edge to the snag or windthrow locations to the distances from the center of the SMZ to the snag or windthrow locations. *t*-Tests were performed for each cutting method separately using each windthrow or snag observation. Pearson's correlation coefficients were used to determine if snag densities were correlated with SMZ width.

**Table 1**

Mean (standard deviation) living plot tree basal area, forest floor mass, DWD volume and *p* values associated with SMZs and upland plot comparisons in four uncut shortleaf pine stands in the Ouachita Mountains.

Stand characteristic	SMZ	Upland	<i>p</i> -Value
Tree basal area ( $\text{m}^2 \text{ha}^{-1}$ )			
Pine	22.4 (9.4)	22.2 (6.2)	0.955
Hardwood	11.7 (4.5)	7.6 (2.7)	0.006
Total	34.2 (7.2)	29.8 (5.6)	0.092
Forest floor ( $\text{kg m}^{-2}$ )	2.2 (0.4)	2.7 (0.5)	0.049
DWD volume ( $\text{m}^{-3} \text{ha}^{-1}$ )	8.9 (13.1)	9.3 (10.3)	0.922

## 3. Results

### 3.1. Comparison of upland and riparian stand locations

Species richness (19 and 18, respectively) and composition was similar in the SMZs and uplands. Both the SMZ and upland plots were dominated by xeric tree species or species that occur in both xeric and mesic moisture regimes such as red maple (*Acer rubrum* L.) and sweetgum (*Liquidambar styraciflua* L.). Shortleaf pine was the most dominant species in both stand locations. Hardwood composition was similar among plot locations; however red maple and sweetgum had higher average basal areas in the plots located in the SMZs ( $1.6$  and  $2.2 \text{ m}^2 \text{ha}^{-1}$ ) than in the uplands ( $0.3$  and  $0.2 \text{ m}^2 \text{ha}^{-1}$ ). Total tree and hardwood tree basal area were significantly greater in the SMZs than in the upland portion of the uncut control stands, but shortleaf pine basal area was similar in each portion of the stands (Table 1). The differences in red maple and sweetgum noted above accounted for 78% of the increase in the hardwood basal area associated with the SMZs. The basal area of hard mast species (*Quercus* and *Carya* spp.) did not significantly differ ( $p = 0.583$ ) in the SMZ plots ( $7.0 \text{ m}^2 \text{ha}^{-1}$ ) compared to the upland plot ( $6.3 \text{ m}^2 \text{ha}^{-1}$ ). Neither pine ( $p = 0.397$ ) nor hardwood density ( $p = 0.219$ ) significantly differed between the SMZ (289 and 401 trees  $\text{ha}^{-1}$ ) and upland (240 and 445 trees  $\text{ha}^{-1}$ ) plots in the uncut stands. Average quadratic mean dbh of the pine in the SMZ and upland plots were, respectively 31.3 and 34.5 cm while quadratic mean dbh of the hardwood trees were, respectively 15.5 and 18.4 cm.

Although tree basal area was higher in the SMZs, forest floor mass in the uncut control stands was 23% greater in the upland portion of stands than in the SMZs. Differences in DWD between the SMZ and upland plots were small (Table 1) but variation among plots was high in both the riparian and upland portion of the stands.

### 3.2. Comparison of reproduction cutting methods

Reproduction cutting methods had little influence on tree basal area or forest floor mass in the SMZs (Table 2). Differences among cutting methods were generally less than 10%. Variances of DWD among reproduction cutting methods were not homogeneous and could not be transformed to provide homogeneity of variances and thus the nonparametric tests were utilized for this variable. Median plot DWD volume was nearly twice as high in the clearcuts than that in the uncut controls or shelterwood stands, but differences between the treatments were not significant. Comparisons of DWD volume and forest floor mass within 12.5 m of the edge among the different cutting treatments showed similar results to those within the plots as a whole.

The distribution of forest floor mass was relatively uniform within 12.5 m of the SMZ edges regardless of the reproduction cutting method. Forest floor mass at 2.5, 7.5, and 12.5 m did not significantly differ with any reproduction cutting method (Fig. 1). Volumes of DWD consistently decreased within increasing

**Table 2**

Mean (standard deviation) living tree basal area, forest floor mass and snag density in SMZs; median SMZ DWD volume, median SMZ windthrow density, and *p* values 5 years following application of several shortleaf pine reproduction cutting methods in the Ouachita Mountains.

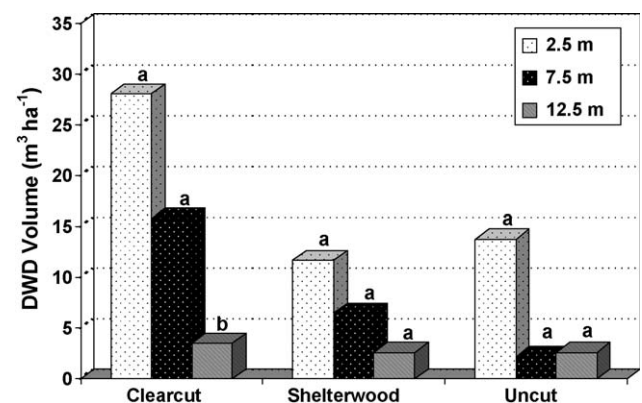
Stand characteristic	Uncut	Shelterwood	Clearcut	<i>p</i> -Value
Midstory and Overstory basal area ( $\text{m}^2 \text{ha}^{-1}$ )				
Pine	22.4 (6.6)a <sup>a</sup>	19.5 (6.4)a	20.8 (2.0)a	0.661
Hardwood	11.7 (2.8)a	9.9 (2.6)a	9.7 (1.6)a	0.501
Total	34.2 (4.6)a	29.4 (5.7)a	30.4 (2.1)a	0.403
Midstory and Overstory density ( $\# \text{ha}^{-1}$ )				
Pine	241 (24)a	242 (74)a	328 (103)a	0.383
Hardwood	445 (52)a	431 (84)a	400 (83)a	0.925
Total	686 (47)a	673 (61)a	728 (21)a	0.265
Forest floor ( $\text{kg m}^{-2}$ )				
DWD volume ( $\text{m}^3 \text{ha}^{-1}$ )	2.2 (0.6)a	2.3 (0.5)a	2.6 (0.5)a	0.564
Snags ( $\# \text{ha}^{-1}$ )	9.0a <sup>b</sup>	8.3a	20.0a	0.358
Windthrow ( $\# \text{ha}^{-1}$ )	39.3 (8.6)a	23.4 (9.9)b	28.0 (10.3)b	0.019
	0.3b	0.0b	11.8a	0.020

<sup>a</sup> Values with the same letter for a given row are not significantly different at  $p = 0.10$ .

<sup>b</sup> DWD volume and windthrow density with the same letter for a given row are not significantly different at  $p = 0.20$ .



**Fig. 1.** Median forest floor mass by distance from SMZ edge and shortleaf pine reproduction cutting methods in the Ouachita Mountains.



**Fig. 2.** Median CWD volume by distance from SMZ edge and shortleaf pine reproduction cutting methods in the Ouachita Mountains (distances with the same letter for a given harvest treatment are not significantly different at  $p = 0.20$ ).

distance from the SMZ edge regardless of the reproduction cutting method (Fig. 2). The nonparametric tests indicated that median DWD volumes at 2.5 and 7.5 m (21.6 and 17.6  $\text{m}^3 \text{ha}^{-1}$ , respectively) from SMZ edges were significantly greater than the median volume at 12.5 m (9.8  $\text{m}^3 \text{ha}^{-1}$ ). Differences in volumes among distances and reproduction cutting treatments

**Table 3**

Mean (standard deviation) distance from the SMZ center and edge to a snag or windthrow location 5 years following application of several shortleaf pine reproduction cutting methods in the Ouachita Mountains.

Stand characteristic	Uncut	Shelterwood	Clearcut
Snag			
Distance to center (m)	9.1 (7.8)	8.5 (5.1)	11.9 (7.1)
Distance to edge (m)	9.8 (7.0)	7.1 (4.2)	10.8 (7.9)
<i>p</i> -Value	0.649	0.289	0.604
Windthrow			
Distance to center <sup>a</sup>			6.7 (5.1)
Distance to edge			7.2 (2.8)
<i>p</i> -Value			0.833

<sup>a</sup> There were not adequate numbers of windthrows found in the uncut and shelterwood stands.

were also significant ( $p = 0.08$ ). Differences in volumes with distances from the edge were most pronounced in the clearcut stands (Fig. 2) where median volumes at 2.5 and 7.5 (28.1 and 15.8  $\text{m}^3 \text{ha}^{-1}$ , respectively) were significantly greater than the median volumes at 12.5 m (3.5  $\text{m}^3 \text{ha}^{-1}$ ). Volumes did not significantly differ among distances for either the shelterwood or uncut stands individually.

Pine and hardwoods were equally represented in the snags that were located, but only one of the 12 windthrows tallied was a hardwood tree. The average dbh of pine and hardwood snags was 18.3 and 16.7 cm, respectively. The dbh of the windthrows were much larger and averaged 25.8 cm. Snag densities were significantly greater within the SMZs established in uncut control stands than either of the harvested stands (Table 2). All but two of the windthrows occurred in the clearcuts, and none occurred in the shelterwood stands. All but one of the windthrows that were located in clearcuts occurred in one stand, but the windthrows in this stand were dispersed uniformly within two SMZs. The two windthrows in the uncut control occurred in only one stand and SMZ. Windthrow densities were not normally distributed due to the high number of transects without windthrows. Median windthrow densities were significantly greater in the SMZs located in clearcuts than in the shelterwood or uncut controls. The magnitude of these differences was large (Table 2).

The distribution of snags and windthrow trees appeared to be independent of the distance from SMZ edges. Although the average distance from a snag to the SMZ edge was less than the average distance from an SMZ center to a snag in the clearcut and shelterwood stands, differences were not significant (Table 3). Average distances from windthrows to edges and centers also did not significantly differ in the clearcut stands.

The density of snags within a SMZ appeared to be related to SMZ width in the uncut stands (Fig. 3). As width of an SMZ decreased the snag density increased, and as a result snag density was significantly and negatively correlated with SMZ width ( $r = -0.372$ ,  $p = 0.047$ ). This relationship was not apparent in the clearcut or shelterwood stands (Fig. 3). Snag density (cases where density was greater than 0) was not significantly correlated with SMZ width in the clearcut ( $r = 0.092$ ,  $p = 0.745$ ) or shelterwood stands ( $r = -0.180$ ,  $p = 0.388$ ).

Due to the small numbers of windthrows, correlations between SMZ width and windthrow density were not calculated. Of the 18 transect located in clearcut SMZs, 6 contained snags. The median SMZ width for the six transects that contained snags was 27.2 m compared to 42.0 m for the remaining transects without snags. A nonparametric Mann–Whitney test indicated that differences between these widths were significant ( $p = 0.018$ ). However, differences in width between transects with and without windthrows for a specific stand did not show this same trend.



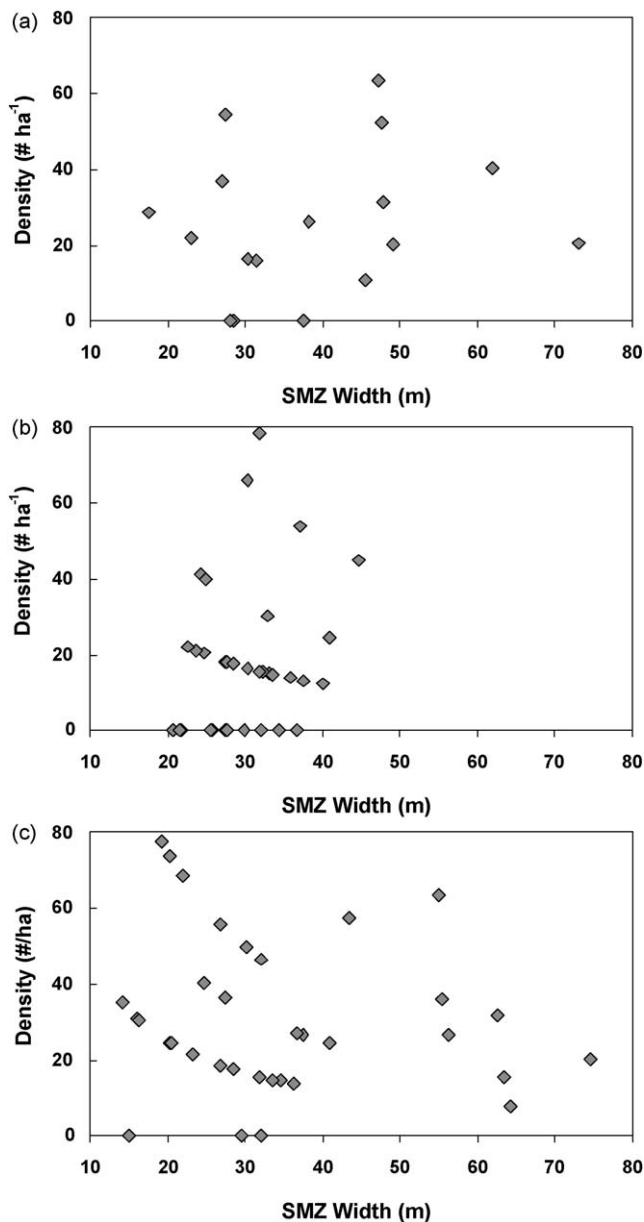


Fig. 3. Snag density and SMZ width in (a) clearcut, (b) shelterwood, and (c) uncut shortleaf pine stands in the Ouachita Mountains.

## 4. Discussion

### 4.1. Comparison of upland and riparian stand locations

Assuming similar levels and frequency of disturbances, trees in the riparian portions of the stands appeared to be more productive than those in the uplands. Plots in the SMZs located in the uncut stands contained approximately 13% more basal area than upland plots. These results differed from those of Radabaugh et al. (2004) who found that midstory and overstory basal area was less in riparian than in upland locations of shortleaf pine stands. Differences may be attributed to the generally lower slope locations of the plots in the study reported by Radabaugh et al. (2004). Stream locations in the lower slopes of the Ouachita Mountains have wider channels or more frequent multiple channels than streams in mid-slope or upper slopes. This increase in channel numbers or size would reduce the available area for tree establishment. Comparisons of riparian forests adjacent to 2nd

order streams in Central Appalachia and upland forests (Murray and Stauffer, 1995) showed higher overstory basal area in the riparian compared to upland forests, but in the Coast Range of Oregon basal area was lower in riparian than in upland forests (McGarigal and McComb, 1992).

If disturbance frequency or intensity differs between these stand locations, differences in basal area may also reflect differences in disturbance. Historically, less frequent harvesting, lower intensity fires, or a less susceptibility to wind damage in the riparian compared to the upland portion of the stands may have resulted in a higher stand basal area in the riparian compared to upland plots. The higher quadratic mean dbh of the trees in the upland plots indicates historic differences in stand density between the two stand locations; however we did not observe any signs of differences in disturbance between the plot locations.

The higher levels of basal area in the riparian plots reflected an increase in the amount of hardwood basal area rather than pine. Radabaugh et al. (2004) also found a higher proportion of hardwoods in shortleaf pine-hardwood riparian forests than upland forests. Although hardwood basal area in the riparian forests was greater than the upland forests, the tree species found in the two areas were very similar. If the increase in hardwood basal area actually reflects an increase in water availability within these riparian forests, these increases were not great enough to support more mesic hardwood species or drastically alter species composition. The riparian portion of these stands did not appear to markedly increase the overall midstory and overstory species diversity in these stands. Hard mast production would appear to be similar in the riparian and upland portions of these forests since the basal area of hard mast species was similar in these two areas. Thus, managers of shortleaf pine-hardwood stands in the Ouachita Mountains could provide similar amounts of hard mast by retaining similar areas of riparian or upland forests. Given the similarity of species composition, density, and diameters of the midstory and overstory trees in the riparian and upland portions of the uncut stands, potential functional differences in these portions of the stands could be minimal.

It was interesting to note that although tree basal area was significantly greater in uncut SMZs than the uplands, forest floor mass was lower. Assuming similar decomposition rates, one would expect that with an increase in tree basal area, litterfall and thus forest floor mass would increase. The reductions in the amounts of forest floor in the riparian areas compared to the uplands may reflect an increase in decomposition rates due to the higher levels of hardwood litter in the riparian portion of the stands. Deciduous broadleaf litter generally decomposes faster than conifer litter (Elliott et al., 1993; Prescott et al., 2000) and rates of decomposition have been found to be greater with pine, deciduous foliage mixtures than with pine foliage alone (Lockaby et al., 1995; Piatak and Allen, 2001). Higher rates of decomposition could also be a result of higher moisture regimes in the riparian components of the stand. Riparian zones frequently have higher soil moistures than adjacent upland areas (Moore et al., 2005) as a result of surface or subsurface water flow. Depressions that accumulate moisture in cool mesic forests have been found to decrease decomposition and increase forest floor accumulation (Liechty et al., 1997), but in more xeric, warmer sites, rates of decomposition are often higher with increases in litter moisture content (Gulevik et al., 2003).

### 4.2. Comparison of reproduction cutting methods

Reproduction cutting methods appeared to have little impact on the basal area or density of living midstory and overstory in the SMZs of the harvested stands. Although others studies have documented increased mortality in stands near the edge of areas that were harvested or that had been cleared for agricultural uses

(Williams-Linera, 1990; Chen et al., 1992; Harper and Macdonald, 2002), we saw no evidence that harvesting had significantly increased mortality of the trees in the SMZs. If mortality had increased we would have expected that tree densities would differ among cutting methods, snag densities would be higher in SMZs within the harvested stands, and/or the average distance from the edge to a snag would be less than the distance from the center of the SMZ to the snag in the harvested stands. Living tree density and differences in snag distance were similar among the three treatments while snag densities were significantly higher in the SMZs located in the uncut stands than in the harvested stands. Mortality in the SMZs during the 3 years following this study (unpublished data) was minimal and similar among the three stand treatments.

Snag and windthrow densities in the SMZs were affected by the reproduction cutting methods employed in the study. Five years after stand harvesting, snag densities were, respectively 38 and 42% less in SMZs located within the clearcut and shelterwood stands than in the uncut stands. Harvesting also impacted the distribution of snags in the SMZs. Snag density was negatively correlated with SMZ width in the uncut stands, potentially due to the location of narrower SMZ in upper slopes within the stands or the more dissected nature of narrow SMZs. However, snag density was not significantly correlated with SMZ width in the clearcut or shelterwood stands. We expect that the changes in snag density were a result of increased snag degradation with harvesting. Harvesting forests can increase the wind speed, solar radiation, and air temperature in riparian zones (Moore et al., 2005). This alteration in climate is likely responsible for an accelerated deterioration of snags and thus a reduction in snag density. A number of other studies have found increased snag breakage and degradation within in a short distances of edges (0–40 m) created by forest harvesting (Harper and Macdonald, 2002; Harper et al., 2004). The effect of harvesting on snag densities may have been the greatest on the narrowest SMZ. The width of these SMZs would be such that the alteration of wind and other climate parameters would have extended across the entire SMZ. It is likely that the severe deterioration of the snags in these narrow SMZ are responsible for lack of relationship between SMZ width and snag densities observed in the clearcut and shelterwood stands.

The reduction of snags in these SMZs has important implications for cavity nesting wildlife. Southern flying squirrels (*Glaucomys volans*) in the Ouachita Mountains commonly use snags for nesting, preferentially nest in SMZs following the harvesting of shortleaf pine-hardwood stands, and have populations that are directly correlated to snag densities (Taulman et al., 1998; Taulman and Smith, 2004). The reduction of snag densities in these SMZs following the regeneration cuttings methods studied would reduce the quality of habitat in these refugia. Potential increases in the width of SMZs or reduction in upland forest removal, may maintain a higher density of snags within these riparian areas and thus support higher populations of wildlife that utilize snags as a critical part of their habitat.

The density of windthrow was also much greater in the SMZs located in clearcuts than in the shelterwood or uncut stands. However, it should be noted that 75% of the windthrows were located within one clearcut stand. Potentially a localized wind event or orientation of the SMZs in this clearcut stand may have contributed to the high level of windthrow. Nonetheless windthrow at the edges of clearcuts are frequently observed in a variety of mature forest ecosystems (Alexander, 1964; DeWalle, 1983; Huggard et al., 1999). Retention of approximately a third to half of the initial basal area in this study may have reduced the windthrow in the SMZ of the shelterwood stands. Other studies have found that while selection harvesting stands may result in

significant levels of windthrow to occur in the harvested stand, windthrow along the stand edges is greatest with clearcutting and increases with size of the clearcut block (Huggard et al., 1999). Retention of approximately  $11 \text{ m}^2 \text{ ha}^{-1}$  of basal area as part of the shelterwood harvest in these shortleaf pine-hardwood stands resulted in similar windthrow densities to that in the uncut controls.

There was no evidence that windthrow more frequently occurs near the edges than interiors of SMZs. However, median SMZ width associated with locations of windthrow was less than locations without windthrow in the clearcuts. Other studies have not found a strong relationship between SMZ width and the occurrence of windthrow. Steinblums et al. (1984) found no significant relationship between buffer-strip width and buffer tree stability in the Cascade Mountains. Ruel et al. (2001) found little differences in the occurrence of windthrow in 20–60 m wide buffer strips when other factors such as buffer orientation were accounted for. It seems likely that retention of some minimal levels of trees in the harvested portion of the stand, as was done in the shelterwood, would reduce the risk of windthrow in the SMZ to a greater degree than would an increase in SMZ width.

Conifers, especially pine, spruce, and firs are thought to be less resistant to wind damage than hardwoods (DeWalle, 1983; Savill, 1983). The greater resistance of hardwoods may potentially be related to the greater bending force needed to fell hardwoods (Curtis, 1943). Shortleaf pine dominated the windthrow that was observed in our study. However, the shortleaf pine growing in the SMZs were much larger (twice the quadratic mean dbh) than the hardwoods. This larger size of the shortleaf pine would result in greater exposure to the force of the wind and thus increased the risk of windthrow of the shortleaf pine compared that of the hardwoods.

Although the amounts of DWD in SMZ did not appear to be impacted by cutting methods, the spatial distribution of DWD was concentrated near the edge of the SMZ with clearcutting. This DWD likely represents slash, tops, and branches introduced in the SMZ during harvesting rather than a result of tree mortality. The rapid decline of DWD towards the interior of the SMZ in the clearcuts suggests that the source of this material came from areas outside the SMZ.

## 5. Conclusions

Within the upland shortleaf pine-hardwood stands of the Ouachita Mountains, midstory and overstory vegetation in upland and riparian areas were similar. Productivity and factors that control forest floor accumulation differed between the upland and riparian areas. Given the similarity of the vegetation, upland and riparian portions of these stands may have similar functions on the landscape. Harvesting the upland portion of these stands can impact snag retention and windthrow occurrence within SMZs. Partial harvests that retain  $11 \text{ m}^2 \text{ ha}^{-1}$  of residual trees may reduce windthrow in SMZs, but this level of residual basal area does not appear to increase snag retention. Although not directly addressed by our study, increasing the width of SMZ may potentially reduce snag degradation and thus increase snag retention.

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